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CALIFA, the Calar Alto Legacy Integral Field Area survey: Early Report.

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Abstract

We present the Calar Alto Legacy Integral Field Area survey (CALIFA). CALIFA's main aim is to obtain spatially resolved spectroscopic information for ∼600 galaxies of all Hubble types in the Local Universe ($0.005< z <0.03$). The survey has been designed to allow three key measurements to be made: (a) Two-dimensional maps of stellar populations (star formation histories, chemical elements); (b) The distribution of the excitation mechanism and element abundances of the ionized gas; and (c) Kinematic properties (velocity fields, velocity dispersion), both from emission and from absorption lines. To cover the full optical extension of the target galaxies (i.e. out to a 3σ depth of μ ∼23 mag/arcsec^2), CALIFA uses the exceptionally large field of view of the PPAK/PMAS IFU at the 3.5m telescope of the Calar Alto observatory. We use two grating setups, one covering the wavelength range between 3700 and 5000 Å at a spectral resolution R ∼1650, and the other covering 4300 to 7000 Å at R∼850. The survey was allocated 210 dark nights, distributed in 6 semesters and starting in July 2010 and is carried out by the CALIFA collaboration, comprising ∼70 astronomers from 8 different countries. As a legacy survey, the fully reduced data will be made publically available, once their quality has been verified. We showcase here early results obtained from the data taken so far (21 galaxies).

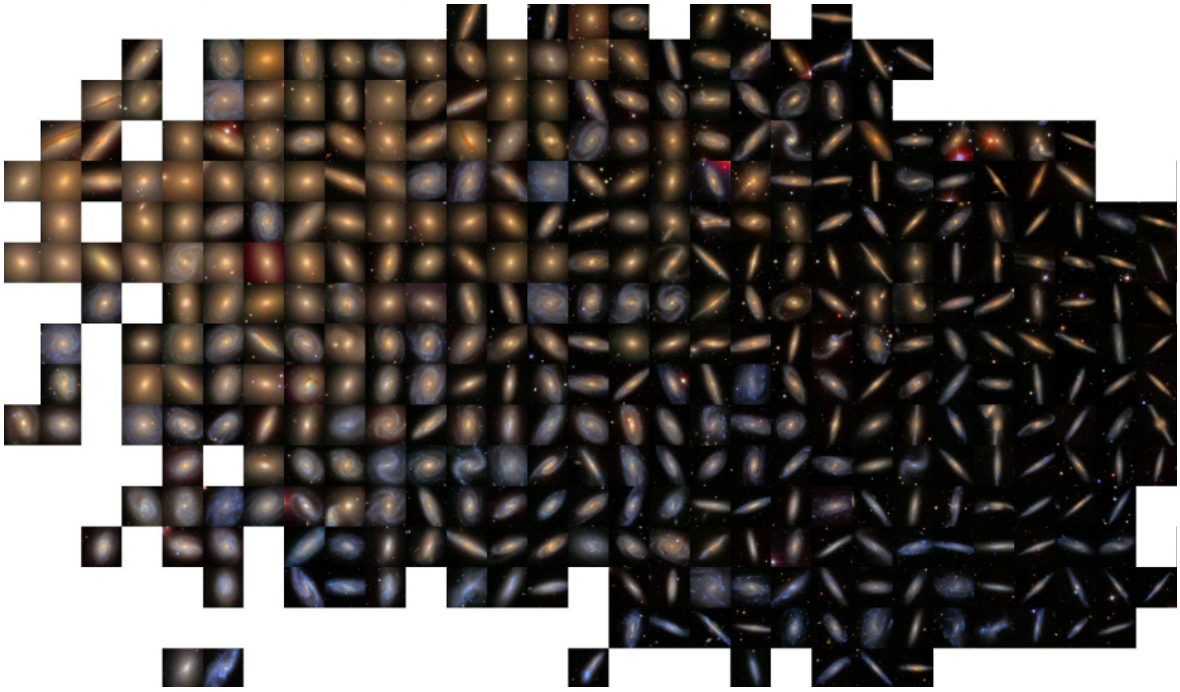

Figure 1: Postage stamp (90"×90") true-color images of a subset of galaxies within the CALIFA mother sample , extracted from the SDSS dataset, ordered following the $u-r$ vs. r color-magnitude diagram. The figure spans from M_r ∼-23 mag from the left end, to M_r ∼-18 mag to the right end, and from $u-r$ ∼3.5 mag from the top end, to $u-r$ ∼1.5 mag to bottom end. The figure illustrates the large variety of galaxy types covered by the survey.

1 Introduction

Much of our recently acquired understanding of the architecture of the Universe and its constituents derives from large surveys (e.g., 2dFGRS, SDSS, GEMS, VVDS, COSMOS to name but a few). Such surveys have not only constrained the evolution of global quantities such as the cosmic star formation rate, but also enabled us to link this with the properties of individual galaxies – morphological types, stellar masses, metallicities, etc.. Compared to previous possibilities, the major advantages of this recent generation of surveys are: (1) the large number of objects sampled, allowing for meaningful statistical analysis to be performed on an unprecedented scale; (2) the possibility to construct large comparison/control samples for each subset of galaxies; (3) a broad coverage of galaxy subtypes and environmental conditions, allowing for the derivation of universal conclusions; and (4) the homogeneity of the data acquisition, reduction and (in some cases) analysis.

An observational technique combining the advantages of imaging and spectroscopy (albeit with usually quite small field of view) is Integral Field Spectroscopy (IFS). However, so far this technique has rarely been used in a 'survey mode' to investigate large samples,

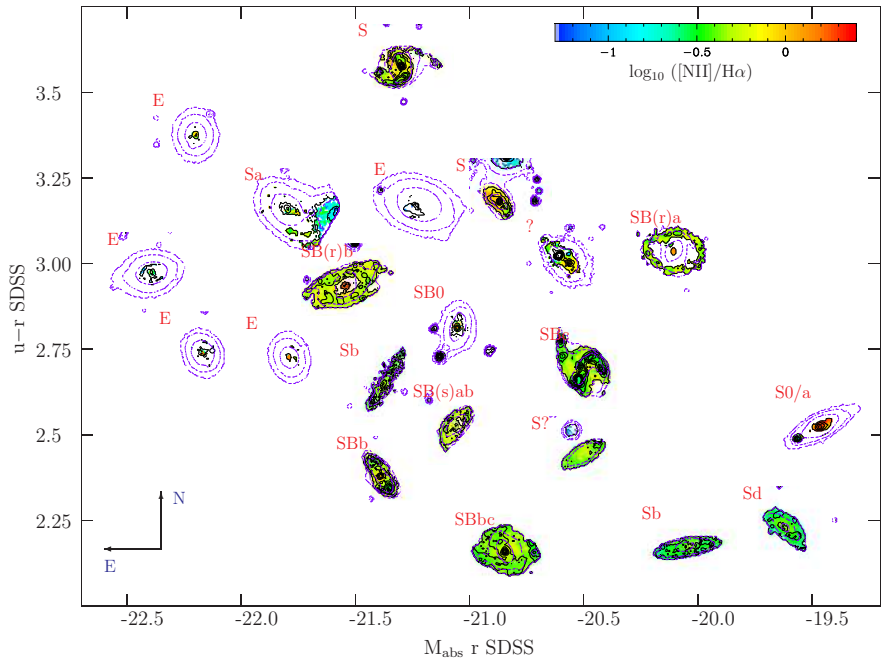

Figure 2: Similar color-magnitude diagram as presented in Figure 1, with the color-maps showing the distribution of the emission line ratios between [NII]λ6583 and Hα, derived by the fitting procedure. In this case the solid-contours show the intensity of the Hα emission. The dashed-blue-contours show 3 intensity levels of the continuum emission at ∼6550Å (starting at 310^{-16} erg s^{-1} cm^{-2}). They have been included to indicate the physical extension of the continuum emission in the galaxies.

with a few notable exceptions (e.g., SAURON, de Zeeuw et al. 2002). On the other hand, the large single fiber surveys mentioned above have limitations that can only be overcome by a statistical sample of nearby galaxies with spatially resolved spectroscopic information. In order to address this requirement, we proposed the CALIFA survey. This survey has been granted with 210 dark nights of the 3.5m telescope at Calar Alto Observatory (Spain), homogeneously distributed along 6 semesters, officially starting the 1st of July 2010. CALIFA will observe a well-defined sample of ∼600 galaxies in the local universe with the PMAS/PPAK integral field spectrophotometer (Roth et al. 2005; Kelz et al. 2006), mounted on the 3.5 m telescope at the Calar Alto Observatory (Spain). The sample to be observed was selected to comprise most galaxy types, covering the full color-magnitude diagram down to $M_B < -18$ mags. The observations will cover the optical wavelength range between 3700 and 7000Å, using two overlapping setups, with resolutions of R∼1650 and R∼850. Considering this spectral coverage, and the large field-of-view of PPAK (>1 arcmin^2), CALIFA is thus the largest and the most comprehensive wide-field IFU survey of galaxies carried out to date.

2 Science Goals

One of the most fundamental challenges in astrophysics is to understand the origin for the observed diversity of galaxies, and the physical mechanisms – intrinsic and environmental – that are responsible for the differences as well as similarities between them. Detailed studies of nearby galaxies can help by revealing structural properties that can be interpreted as "fossil records" of the formation and evolution process. We have long known from our own Milky Way that there are intricate links between chemical and kinematic properties of stellar populations, as well as between stars and gas, and similar relations have been found in other galaxies. An old but still unanswered question is the problem of "nature vs. nurture", i.e. the relative importance of environmental processes such as merging and accretion, relative to intrinsic secular processes that inevitably occur in an evolving complex dynamical system. A more recently posed puzzle is the origin of the bimodality of the galaxy population. What is it that makes galaxies be either "red and dead" or "blue and star forming", and in particular, what is happening to galaxies in the intermediate "green valley" of the color-magnitude diagram? An important contribution to progress in these areas can come from spatially resolved spectroscopy of a statistical sample of galaxies, such as will be provided by the CALIFA Survey. In the following we list a few specific questions that CALIFA will allow us to address:

- Characterization of galaxies over their *full* spatial extent, i.e. avoiding aperture biases and harnessing the additional power of 2D resolution (gradients, anomalies).
- The environmental dependence of the stellar populations in the *outskirts* of galaxies, where they are most likely to be affected (e.g. origin of disk truncation).
- Gas ionization mechanisms (star formation, shocks, AGN) in dependence on location inside the galaxy and galaxy overall properties.
- Kinematic classification of galaxies of *all* Hubble types, e.g. are there dichotomies similar to the slow vs. fast rotators also in late type galaxies?
- Chemical evolution of *entire* galaxies and the origin of the scaling laws of gas metallicity (through e.g. abundance gradient dependance on internal and external properties).
- The nature of the galaxies in the green valley, e.g. whether galaxies stop forming stars from the outskirts or from inside out.
- Finally, comparison to full chemo-dynamical models, i.e. weighing in the relative importance of dynamical processes (bars, minor mergers, migration etc.) and star formation processes (feedback, stellar evolution, etc.) for the chemical enrichment processes in galaxies.

To address these scientific questions, we have designed the survey so it allows us to make three key measurements: (a) Two-dimensional maps of stellar populations (star formation histories, chemical elements); (b) The distribution of the excitation mechanism and

element abundances of the ionized gas; and (c) Kinematic properties (velocity fields, velocity dispersion), both from emission and from absorption lines. All these quantities will be reconstructed in maps covering the entire luminous extent of the galaxies in the sample, a first in galaxy evolution studies.

3 Sample

The CALIFA mother sample has been tailored to fulfill the main requirements of the science goals of the survey, i.e., the characterization of the spatially resolved spectroscopic properties of galaxies in the Local Universe of any kind, on one hand, and to maximize spatial coverage of the IFU over the complete size of the galaxies, on the other. Based on these requirements and to guarantee good photometric coverage, the mother sample has been selected from the SDSS DR7 photometric catalogue (Abazajian et al. 2009), adopting a combination of angular isophotal diameter selection ($45'' < D25 < 80''$) with redshift selection ($0.005 < z < 0.03$). The final mother sample comprises ∼1000 galaxies, and is a representative subsample of the galaxies in the Local Universe (Mast et al., in prep). The final observed sample by CALIFA will be selected from this mother sample, based on the visibility for each night. It is expected that this will produce a random subsample of ∼600 galaxies.

Figure 1 shows postage stamp images of a random selection of galaxies within the mother sample, distributed along the color-magnitude diagram, illustrating the diversity of galaxies and the wide range of parameters covered by the survey (∼5 magnitudes in luminosity and ∼3 in color).

4 State of the Survey

CALIFA has recently started. Its data acquisition phase will last for three years, and we have just got data for 21 galaxies (June-July 2010). The reduction of the CALIFA data is performed using a fully automatic pipeline, that operates without human intervention, producing both the scientificaly useful frames and a set of quality control measurements that help to estimate the accuracy of the reduced data. The pipeline uses the routines included in the R3D package (Sánchez et al. 2006) and the E3D visualization tool (Sánchez et al. 2004). The reduction consists of the standard steps for fibre-based integral-field spectroscopy.

The first acquired data have been fully reduced using the implemented pipeline. To determine their quality, a set of exploratory analyses were performed in order to derive the three key measurements that drive the survey: stellar population properties, ionized gas properties, and kinematic information in both components. For this exploratory analysis we adopted procedures based on FIT3D (Sánchez et al. 2007), described in detail in Sánchez et al. (2010), and used in previous surveys (eg., PINGS, Rosales-Ortega et al. 2010). It is expected that the final analysis of the CALIFA data will also use a large number of other tools, both from within the collaboration and from the scientific community.

Figure 2 showcases one of the outputs of this analysis. We show there the spatial distribution of the [NII]/Hα emission line ratio (a classical ionization diagnostic parameter),

for the different observed galaxies, distributed along the the color-magnitude diagram. This figure illustrates the kind of comparative analysis that can be performed with CALIFA, where different spatially resolved spectroscopic properties of different families of galaxies can be compared in an homogenous way. In particular, in this figure one sees (i) red and dry galaxies, with little or no gas, most of them luminous early types; (ii) bluer and more gas rich galaxies, with a wider variety of morphologies, and with extended starforming regions and (iii) galaxies clearly dominated by AGN activity, with gas ionization concentrated in the central regions ([NII]/Hα>1).

5 Summary

We have presented the CALIFA survey, the largest IFU survey currently being implemented. The results of this survey will allow us to make significant progress in many areas of galaxy evolution where large, single-fiber surveys are limited through a lack of spatial resolution and aperture biases. We will progressively report on the development of the survey in subsequent articles, and through its webpage HTTP://WWW.CAHA.ES/CALIFA.

Acknowledgments

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